

High Energy Physics at LBNL:

Status and Outlook

November 2005

Executive Summary

The High Energy Physics program at LBNL, comprising the entirety of the Physics Division and a portion of the Accelerator and Fusion Research Division (AFRD), brings a unique combination of university and laboratory resources to the international high energy physics program. This document provides a brief summary of the current research program at LBNL, our relationship to other high-energy physics institutions, and our plans for future work.

The Berkeley HEP program in the Physics Division makes essential contributions in four broad scientific areas: at the energy frontier through the search for the origins of mass; in the quark flavor mixing sector through the search for the mechanisms of CP violation; in the lepton flavor sector through the study of flavor oscillations of reactor and solar neutrinos; and in particle astrophysics through the study of dark matter and dark energy. These flagship science efforts are complemented by theoretical studies, and the activities of the Particle Data Group. AFRD provides a foundation for current and future accelerator programs. The priorities of the Berkeley effort are directly aligned with those of the national program.

In each of our major experimental efforts, SNAP, ATLAS, BaBar and CDF, the Physics Division makes significant and essential contributions. In addition, LBNL leads the Particle Data Group, the US KamLAND collaboration, and participates in Linear Collider (LC) detector R&D. LBNL's historical role has been one of physics from 'start to finish'. We participate in the conception, design, construction, commissioning, operation, physics analysis and upgrades in our experiments. The support and facilities of the Laboratory allow us to carry these roles very effectively in a way not possible even in large university groups.

The future program at Berkeley can be reliably extrapolated from the natural development of the ongoing activities. Our physics program will increasingly focus on exploration of the energy frontier, and determination of the nature of Dark Energy. Particle cosmology and ATLAS have become the largest components of the Physics Division program. Neutrino experiments will be a joint effort between the Lab's Physics and Nuclear Science Divisions. R&D efforts for both instrumentation and computing will be ongoing. We anticipate contributions to the development of the Linear Collider physics case as the next major element of the International Accelerator Program. The Linear Collider accelerator efforts will grow commensurate with those of the national linear collider collaboration.

Berkeley has helped to shape high-energy physics in the US over the past decades and is making crucial contributions to the program today. Among the notable achievements are the invention of the TPC, pioneering work in silicon strip detectors and their electronics for both hadron and electron-positron colliders, the invention of the asymmetric electron-positron collider, the development of supernova cosmology and subsequent discovery of dark energy, the development of thick, fully depleted, infrared sensitive CCDs for astronomical applications, and the development of pixel technology for LHC. This record of innovative performance highlights our scientific achievements.

1 LBNL Role in U.S. HEP program

The goal of the LBNL HEP effort is to provide innovation and leadership for the U.S. HEP program through the maximum usage of the unique capabilities available in a large national laboratory closely tied to a major university. LBNL staff and U.C. Berkeley faculty work closely together utilizing the excellent experimental laboratory facilities, engineering and fabrication facilities and state-of-the-art computing resources available at the Laboratory. The participation of a large number of excellent graduate and undergraduate students who are part of the University enriches the program.

Major HEP experiments require the fabrication and operation of complex particle detectors and the manipulation of huge sets of data, and LBNL, working in collaboration with numerous universities, is playing a major role in several of these experiments, including ATLAS, BaBar and CDF. LBNL is leading the SNAP program to determine the characteristics of the Dark Energy.

LBNL has played a major role in the development of large detectors for Fermilab, SLAC and the LHC. It was a lead institution bringing the silicon strip vertex detector technology in CDF through the development of the crucial readout chip. This work had a major impact on the top quark discovery, and led to the use of silicon trackers in virtually all collider detectors. LBNL's strength in IC engineering was also instrumental subsequent upgrades of the CDF vertex detector, in the success of the BaBar drift chamber and SVT, and is now enabling the development of large scale focal plane electronics for space in the SNAP experiment. LBNL was responsible for the design and construction of mechanical systems for both the DIRC particle ID and the SVT silicon systems for BaBar, and was responsible for SVT final assembly and installation. In ATLAS, LBNL has taken leadership responsibilities in both the silicon strip system and the extremely challenging pixel system, and is collaborating with many university groups on their construction. LBNL responsibilities include both electronic and mechanical aspects, and again engineering support is playing an essential role.

LBNL also plays a very prominent role in the HEP community. Bill Carithers is the current chair of the DPF and Natalie Roe has been elected vice chair. Roe is on NUSAG and the URA visiting committee for FNAL. Jay Marx is on P5 and on many other panels. Bob Cahn chaired the RSVP scientific assessment committee (Roe was also a member) and is on the Dark Energy Task Force. Cahn and Saul Perlmutter are members of HEPAP. Hitoshi Murayama is on the FNAL PAC and the DPF Executive committee.

2 Physics Division Programs

2.1 Exploration of the Energy Frontier

Accelerator-based exploration of the energy frontier plays a central role in the LBNL physics program. At the present time, the CDF experiment at the Tevatron forms the center of this effort through a program of precision measurements of electroweak parameters. In 2007, the ATLAS experiment at the LHC will become the premier facility for such exploration. Further in the future, the Linear Collider will complement LHC research.

2.1.1 CDF

The CDF group at LBNL has contributed heavily to physics analysis for many years: discovery of

the top quark, first measurement of the top quark mass, particle searches, W mass, W and Z cross sections. Members of the CDF group had leadership roles as conveners in many analysis subgroups: B physics group, jet corrections, Higgs, B-tagging and semi-leptonic B physics. Presently, the group has limited resources as at LBNL the effort has been shifted towards the ATLAS program. Only two postdocs and a fellow remain and six PHD students. One postdoc is the leader of the W+jets top group. Presently the effort is concentrated on B physics and top physics studies. Most of these analyses exploit the silicon vertex detector that allows tagging of B hadrons.

Accomplishments of the LBNL group during this year include:

- Measurement of Z and W cross sections and of Z decay asymmetry (PHD thesis).
- Measuring the top cross section in Run II (PHD thesis).
- Improvement of systematic errors on measurements of jet energies, essential for precision measurement of the top mass. (work continuing).
- Measurement of the top quark mass, which is the best measurement published so far (PHD thesis).
- Search for new particles decaying into bb, in particular cross section upper limit for Standard model Higgs production at the Tevatron.
- Improvement of the b-tagging algorithm by using a Neural Network method (work in progress), which is essential for top quark measurements as well as for particle searches.

Papers on the first five items have been published or submitted for publication. Three PHD students are engaged in the present program on top quark studies.

2.1.2 ATLAS

LBNL has been a pioneer in the development of new silicon detector technologies for high-luminosity hadron colliders. The LBNL group is continuing this role and is currently leading the U.S. effort to develop and fabricate silicon pixel detectors for ATLAS. The design of the critical front-end integrated circuits for the ATLAS pixel detector was largely an LBNL responsibility. LBNL also has the major responsibility for the design and fabrication of the pixel thermal and mechanical structure, which has required the development of new concepts. The overall support structure for the pixel system is an LBNL responsibility as is fabrication of about one-third of the active detector elements, modules, and the corresponding mechanical supports.

In addition, LBNL, in collaboration with the University of California Santa Cruz, has completed fabrication and testing of about one-third of the silicon strip detector modules for the central (barrel) region of ATLAS. A sophisticated system has been designed and fabricated at LBNL for testing the large number of integrated circuit wafers for the ATLAS silicon strip detector. The barrel part of the silicon detector has been assembled at CERN and preparations for the installation are underway.

The LBNL group has had a seminal role in understanding the physics signatures at high luminosity hadron colliders. This work began in the 1980's and is continuing now for ATLAS. LBNL has a coordinating role in the development of the ATLAS physics simulation program. This ensures a close tie between the technical aspects of the experiment and the rich physics potential of the LHC.

The software and computing expertise available at LBNL is now being utilized to lead the development of the framework code (ATHENA) that will provide the backbone of the ATLAS

software. This work builds on the experience of CDF and BaBar, and takes advantage of the strong team of physicists and computing professionals that has been brought together at LBNL.

Specific accomplishments at LBNL in the past year include:

- Completion of silicon strip module fabrication and delivery of detectors to Europe.
- Completion of pixel module fabrication and start of final system assembly
- Delivery of the first pixel items to CERN
- Major leadership roles for LBNL, including election of Kevin Einsweiler as pixel project manager, and reelection of David Quarrie as ATLAS software coordinator
- Major role in management of the production of simulated data samples for the annual ATLAS physics workshop in Rome, Italy.

2.1.3 Linear Collider (LC)

The Berkeley group has participated in the development of the community consensus in favor of the LC over the past few years. LBNL's Marco Battaglia has initiated a new R&D effort on silicon detectors for the LC. In addition, we have been active in studies of TPC hardware for application at LC. We have collaborated with nuclear physicists interested in upgrades of the STAR experiment at RHIC in order to form a critical mass of researchers in the area of detector R&D.

2.2 Quark and Lepton Flavor Studies

2.2.1 BaBar

LBNL has played a major role in all aspects of the BaBar experiment beginning with the proposal to use asymmetric beams to make precise measurements of CP-violation in B decays. During the construction phase, LBNL had leadership responsibility for the Silicon Vertex Tagger (SVT), led the mechanical construction of the Detector of Internally Reflected Cherenkov light (DIRC) and was responsible for the Charged Track Trigger and Drift Chamber Readout. In addition, LBNL led the original development of code for track reconstruction and was responsible for much of the software framework. Most recently LBNL led the design and implementation of a new computing model, which has significantly increased analysis speed and has permitted the collaboration to increase its physics productivity.

Among the achievements of the LBNL BaBar group during the past year are the following:

- Significant progress in unfolding the hadronic mass spectrum in $b \rightarrow u$ semileptonic decays.
- Clean extraction of D , D^* , and D^{**} in semileptonic B decays, leading to an improved result for V_{cb} .
- Completion of the analysis of the form factors in $B \rightarrow D^* l \nu$.
- Development of a framework to improve tracking, exploiting earlier LBNL work on mini-dst and Computing Model II.
- Preparation of publications on the full data set for the analysis of $B \rightarrow VV$ decays. LBNL's work on the $p\bar{p}$ final state has provided the best measurement of the angle α of the unitarity triangle.

2.2.2 CDF

At the Tevatron, there remains unique physics to be done in the areas of CP violation, CKM matrix element measurements, and many other measurements of properties of B hadrons. The LBNL group has been heavily involved in B physics analysis for many years, contributing to the detection of several B decay modes and to mass and lifetime measurements (including the B_s lifetime). LBNL has also contributed to work towards measurements of B_d mixing and observation of time dependence of mixing. In Run II the LBNL initial physics interest is centered on precision measurements of CKM matrix parameters and properties of B hadrons. The group has contributed to measurement of several branching fractions of B hadrons. The group has recently published a measurement of the hadronic moments of semileptonic decays of charged B mesons which provide constraints on QCD corrections to $|V_{cb}|$. This puts to use the expertise of the group, including detailed knowledge of the hadronic trigger that uses the SVT (silicon vertex trigger), and prepares the group for more complex measurements.

The group is presently working on the measurement of a Cabibbo suppressed B decay that could lead to measurement of the angle γ of the CKM unitary triangle (one student PHD thesis). The group is contributing in several ways to B_s mixing studies. The LBNL group has been working on full reconstruction of B_s decays, concentrating on improving the significance of the x_s mixing parameter. New upper limits for x_s have just been obtained. Two PHD students are working on the B_s mixing measurement.

2.2.3 KamLAND

The KamLAND experiment exploited the old Kamiokande underground site and the presence of a large number of nuclear power reactors in Japan. The LBNL-led US KamLAND Collaboration proposed several initiatives designed to make this experiment robust against potentially crippling backgrounds and to increase its sensitivity still further, enabling it to eventually measure directly solar neutrinos from ^7Be .

The one-kiloton liquid scintillator target/detector results in approximately 300 neutrino events per year from the reactors, many of which are 140 to 200 km away. The very large ratio of this distance to the neutrino energy enables KamLAND to reach two orders of magnitude further in Δm^2 than any previous reactor experiment, making it the first terrestrial experiment to address the solution to the solar neutrino problem and to observe disappearance of reactor antineutrino due to neutrino oscillation. Recently, KamLAND also observed geoneutrinos for the first time, creating a new window to explore the interior of Earth.

LBNL's contribution to the experiment, in addition to management and oversight (with UCB) of the US part of the collaboration, centered on the development of specialized waveform-capture electronics ideally suited to KamLAND's needs. LBNL has completed the construction of a new calibration system that can sample most of the fiducial volume of the detector. Installation of this system is underway. LBNL is also building an external muon identifier to help understanding the cosmic-ray muons and their produced backgrounds in the KamLAND detector. In addition, studies of the KamLAND liquid scintillator are in preparation. .

2.3 Dark Energy and Dark Matter

The Berkeley astrophysics programs have had a very significant impact on recent discoveries and on definition of the future program. The discovery that 95% of the universe is composed of dark matter and dark energy, neither of which is described by the Standard Model, gives a clear focus to the program.

2.3.1 *Supernova Cosmology Project and the Nearby Supernova Factory*

The LBNL Supernova Cosmology Project (SCP) was the first group to show how distant supernovae could be discovered on a reliable basis, and how their brightness and redshift could be properly interpreted to measure fundamental cosmological parameters. These data gave the first evidence that the geometry and fate of the Universe do not conform to expectations. These astonishing conclusions are the impetus for further studies to reduce systematic errors and to probe more deeply the physics that underlies these phenomena. LBNL scientists are working with other groups to study supernovae at high redshift using ground-based telescopes and the Hubble Space Telescope. At the same time, more low-redshift type Ia supernovae are needed for systematic studies, and a broad effort for this is already underway.

The Nearby Supernova Factory (*SNfactory*) has been designed to lay the foundation for current and next generation experiments to determine the properties of Dark Energy. It will discover and obtain lightcurve spectrophotometry (simultaneous broadband lightcurves *and* spectral time series) for more than 300 SNe Ia supernovae in the low-redshift end of the smooth Hubble flow. Their statistical power alone will lower the statistical error of the current SCP results by up to 50% and will help reduce the systematic error. In the longer term, they will improve *SNAP's* constraint on Ω_M by 40% and on w_0 by a factor of two.

There was substantial progress in all aspects of the project in 2005 and the Supernova factory is now well on the way to realizing its scientific goals. To find large numbers of supernovae, the project uses repeated scans of a large area of sky with an automated telescope. A search program then scans thousands of images looking for new objects that suddenly get much brighter in the sky, indicative of a massive explosion. This program has been extensively refined over the past year and is now able to process each night's data and identify candidates in almost real time. Once a new supernova is identified, detailed measurements are performed with a unique spectrograph that was built for the project by French collaborators and was successfully commissioned this year at the University of Hawaii telescope on Mauna Kea.

In the past year, the SCP and SNfactory projects have:

- Found and spectroscopically confirmed 45 SNe
- Spectroscopically confirmed an additional 60 SNe from the International Astronomical Union Circulars
- Observed 18 IAU SNe Ia with multi-epoch spectroscopy showing how supernovae evolve with time
- Observed 10 SNfactory Ia's with multi-epoch spectroscopy
- Obtained HST UV imaging for 4 SNe Ia
- Obtained Infrared imaging and/or spectroscopy for an additional 9 SNe Ia.

2.3.2 *SNAP/JDEM*

With a 2m telescope and 600-million pixel imager, SNAP (Supernova/Acceleration Probe) could discover and obtain high-signal-to-noise calibrated light-curves and spectra for over 2000 Type Ia supernovae at redshifts between $z = 0.1$ and 1.7 . This would help eliminate possible alternative explanations, give experimental measurements of several other cosmological parameters, and put

strong constraints on possible cosmological models. The imager would use the CCD developed by the Physics Division. These CCD's have a high resistivity substrate with excellent quantum efficiency at long wavelengths. Their development was a direct spin-off of previous investments in SSC detector technology.

For the past 4 years, LBNL has carried out a broad program of R&D to define the science case for SNAP and to develop the technologies needed to realize the program. In November 2003, NASA and DOE announced a Joint Dark Energy Mission (JDEM) for which the SNAP collaboration will compete. LBNL scientists are members of the Science Definition Team for JDEM. As this team continues its deliberation, the plan and schedule for these studies will become clear.

Over the past year the project has had major successes in the development of two complementary technologies needed for the project, and both technologies now meet or exceed the specifications required for the mission. One of the key technologies is thick, fully-depleted p-channel CCDs that have high quantum efficiency extending from 400 to 1000 μm , and that will survive in the severe radiation environment of space. Working with a commercial CCD foundry, LBNL scientists have produced science-grade devices that meet all SNAP needs. In a collaboration with the UC Lick Observatories, the scientists are further testing the new chips in ground-based astronomy. LBNL is also collaborating with the FNAL-led Dark Energy Survey (DES) by providing 70 science-grade CCDs for a large new focal plane to be deployed at the 4m Cerro Tololo telescope in Chile. The second key technology is detectors that work in the Near Infra Red (NIR), from 1000 to 1700 μm . These are crucial because, for very distant supernovae, the lightwaves have been stretched (or red-shifted) as the universe expands, resulting in light that is redder than can be measured with CCDs. Working with two major industrial partners, the collaboration has now developed new detectors that meet the exacting demands of the mission. In addition to detector development, the SNAP team is developing custom ICs for detector readout that will enable very large numbers of detectors to be deployed within the tight spatial and power constraints of a space mission

2.3.3 *Cosmic Microwave Background*

The primary focus for the current CM program is instrumentation for experiments with large format bolometer arrays. APEX-SZ and the South Pole Telescope will utilize the Sunyaev-Zel'dovich (SZ) effect to search for distant galaxy clusters. The distribution of galaxy clusters vs. redshift is sensitively dependent on Ω_M , Ω_Λ , and w . Unlike x-ray or optical surveys, the magnitude of the SZ signal is independent of redshift, so it is well-suited for deep searches. These experiments are complementary to SNAP as they attack the same physics with a completely different technique.

Complementing these instrumentation advances is a vigorous theory and data analysis effort. Currently it is focusing on the analysis of MAXIPOL (the polarization sensitive successor to MAXIMA) data and the development of algorithms for the analysis of the Planck satellite data. The new science and the large data sets expected from APEX-SZ, and POLARBEAR will require an expansion of our theory effort.

2.4 Theory

The Particle Theory Group, including its LBNL and Berkeley campus components, is one of the world's leading research groups and an important center for the training of students and postdoctoral fellows. The traditional coherence of theoretical research with the experimental program of the Physics Division is a special strength of the LBNL group. LDRD and campus

support for the theory group has allowed stabilization of theory efforts through funding of the theory center on campus. Research is carried out in the Theory Group over a very broad range of subjects, ranging from M-theory to phenomenological studies of immediate importance to experiments, especially ATLAS and BaBar. Recent work by Berkeley theorists and their collaborators show an increasing focus on the physics of the LHC. Hall and collaborators have addressed the naturalness problems of the Standard Model by constructing new models of the Higgs sector that can be tested at the LHC. Nomura and collaborator have shown within the Minimal Supersymmetric Standard Model that a natural solution to experimental constraints from LEP is achieved in which the dark matter candidate (lightest supersymmetric particle) is sure to have an observable signal in cold dark matter searches, which can be confirmed by observations at the LHC. Bauer and Schwartz are applying the methods of Soft Collinear Effective Theory, which was developed and fruitfully applied in the area of heavy flavor physics, to the study of jet physics at the LHC. Their long-term goal is to develop an efficient multiloop event generator for the LHC.

2.5 Particle Data Group

For fifty years the Particle Data Group has provided essential up-to-date summaries of experimental and theoretical particle physics and, more recently, cosmology, to the physics community and to teachers and students. Reviewers have stated:

“The work of the PDG is absolutely necessary for rapid progress of elementary particle physics. Without it, the field would be very fragmented and achieving consensus would be very difficult.”

“This effort is invaluable and must be supported. This is constantly being improved and expanded.”

“The Particle Data Group has continued to provide the outstanding and essential service that the scientific community has become used to expect, and has once again confirmed and reinforced the unique role of the RPP as the central and authoritative source of reference data in particle physics.”

LBNL is the headquarters of this large international effort covering particle physics and cosmology via reviews and data summaries. The PDG consults with over 700 physicists throughout the world to obtain expertise on data and specialized topics, and to insure that the summaries reflect the current viewpoints of the community. An international advisory committee reviews all content and operations annually. The information is made available through the biennial publication of the “Review of Particle Physics” (an 1100-page journal publication), and the “Particle Physics Booklet.”

The Particle Data Group has a large impact in science education and awareness. The “Review” and “Booklet” are used by thousands of students and teachers. The PDG is a leader on several national and international educational projects including the QuarkNet program, the Contemporary Physics Education Project, the award-winning “Particle Adventure” website, the ATLAS Experiment, the “Universe Adventure” website, and the Nobel Foundation’s eMuseum. These projects make particle physics and cosmology accessible to non-scientists and enable high school and college teachers to address these topics in introductory physics courses.

3 Future Directions for the Physics Division Program

Our physics future will increasingly focus on accelerator-based exploration of the energy frontier, and determination of the nature of the Dark Energy. Particle cosmology and ATLAS have become the largest components of the Physics Division program. We expect to maintain the diversity of our program with a complementary effort in neutrino physics, which will be a joint effort with the Nuclear Science Division. R&D efforts for both instrumentation and computing will be

ongoing. The Linear Collider efforts will grow commensurate with the national linear collider collaboration.

In early December, the Physics Division will hold a two-day planning retreat to reassess its priorities and to discuss how to maintain the excellence of its program within the budget constraints imposed by the DOE. The retreat will look at the current accelerator-based and astrophysics programs as well as possible new initiatives. While we do expect that the retreat will lead to some changes in our program, we expect that the following efforts will remain active for the next few years.

3.1 Dark Energy, Dark Matter and Cosmology

Recent studies of high redshift type Ia supernovae (SNe) observed with the Hubble Space Telescope (HST) and ground-based telescopes confirm the Supernova Cosmology Project's (SCP) well known 1998 result, which, based on a sample of 42 type Ia supernovae, excludes a simple $\Omega_M = 1$ flat universe and presents strong evidence for the existence of a cosmological constant ($\Omega_\Lambda > 0$) or a dynamical near-equivalent. To fully exploit the use of SNe Ia as cosmological probes and to study the "dark energy" that is causing the acceleration of the universe's expansion, a space-based telescope such as SNAP is needed. The conceptual design and requisite R&D for such a space mission form a large part of our program. For continued studies of SN Ia cosmology while SNAP is being prepared, the SCP will continue its program of supernova search/identification/and follow-up campaigns in the mid- to high-redshift region employing coordinated multi-epoch observations using the most powerful ground-based telescopes and the Hubble Space Telescope (HST). However, these high redshift studies will be completely dominated by known and potential systematics unless SNe Ia are better calibrated and scrutinized far more closely for (as yet undetected) systematic effects and towards this end we are running the Nearby Supernova Factory (SN Factory) which will provide a major improvement on the low- z end of the Hubble diagram ($0.03 < z < 0.08$) by providing a substantial increase in statistics and greatly improved control of systematics.

3.1.1 Supernova Cosmology Project and the Nearby Supernova Factory

The goals of the SCP program are to add statistics to the middle region of the Hubble diagram ($.3 < z < .8$) and extend it to $z > 1$. Prior to SNAP, such studies can provide a measurement of the dark energy equation of state, $\langle w \rangle$ (time average) that is limited in precision, but may still be able to distinguish a cosmological constant ($w = -1$) from alternative models. The SCP is collaborating with a major five-year legacy survey using the Canada-France-Hawaii Telescope that will yield hundreds of SNe Ia in the mid-redshift range.

A second focus of the current program is to use HST to study SNe with $z > 1$. Though the statistics of these very high z SNe will necessarily be small due to the limited field of view of the HST, such events will be of great interest as they allow us to look back to the acceleration/deceleration transition era.

The Nearby Supernova Factory will discover and obtain lightcurve spectrophotometry for more than 300 SNe Ia supernovae in the low-redshift end of the smooth Hubble flow. This SNe dataset will further serve as the premier source of calibration for the SN Ia width-brightness relation and the intrinsic SN Ia colors used for correction of extinction by dust (needed by SCP and SNAP). This dataset will also allow an extensive search for additional parameters, which influence the quality of SNe Ia as cosmological probes. Well-observed nearby SNe Ia, especially in host

galaxies spanning a wide range in star-formation histories, are essential for testing for possible systematics. Following the successful commissioning of SNIFS in late 2004, the project is ready to carry out its program of supernova studies.

3.1.2 SNAP

In November 2003, NASA and DOE announced an agreement to fund a Joint Dark Energy Mission (JDEM) with a competitive process to select a mission in 2006. This decision has significantly changed the course of the SNAP program at LBNL and within the collaboration. NASA and DOE have formed a Science Definition Team and LBNL is very active in that effort. Three LBNL scientists from SNAP are on the team, and they are supported by the simulation efforts within the SNAP collaboration. In addition, the SNAP detector R&D effort is now critically important.

The SNAP science hinges on the reach to high redshift supernovae and precision weak lensing measurement only achievable in space. Realization of the science requires state-of-the-art photodetectors in the visible to near infrared (NIR) wavelengths (0.35 – 1.7 μm). A DOE review noted that this is “the most ambitious detector focal plane ever proposed, for ground or space.” With the investments we are making in the R&D period, we can advance these devices into the enabling technologies required for the SNAP science program. If we fail to ready these technologies in time, the science reach of SNAP will be reduced and its ability to successfully compete for JDEM will be compromised. The recent technical review in Nov. 2003 by outside experts emphasized this point: “With the recent re-direction to JDEM, it is very important to re-focus and heavily emphasize work on advancing key technologies. Detectors and electronics are likely *the* highest risk area in the mission concept. The visible arrays, and especially the near-IR arrays, are not in the bag.”

The SNAP team has continued to refine and focus the R&D program. Our efforts are now focused on developing the science, the technologies, and the mission assurance and management plans in time for the JDEM Announcement of Opportunity, to be issued and competed by DOE and NASA. The overall scope of the R&D program has been refined to take into account the process by putting enhanced effort into simulations to understand various mission concept trade-offs. These studies will be key inputs to the JDEM Science Definition Team. We are carrying out an optimization across the total scientific mission, including the telescope, focal plane, and science simulation to establish scientifically driven requirements. We also plan to respond to the NASA call for JDEM Advanced Mission Concept Study proposals with a proposal that will focus on bringing NASA expertise to bear on the mission management and assurance aspects of the program. This integrated approach to Dark Energy science is the focus for the SNAP R&D period.

The SNAP program and the impact of delays in JDEM are major concerns for us. We believe that, the SNAP collaboration must maintain an aggressive R&D effort. The reasons for this are as follows:

With the recent release of the NASA ROSES competition for the mission concept studies for JDEM, SNAP is now under enormous competitive pressures. The intent of this solicitation is “to provide sufficient support for the development of collaborations with independent approaches”. The Goddard Space Flight Center (GSFC), which has already been guaranteed by NASA & DOE to manage the mission concept studies for the JDEM program, has consequently launched a very aggressive plan to capture the dark energy investigation as well. Goddard is currently supporting two separate dark energy proposals with Goddard as the lead. Goddard recently hired the PI from a competing team (DESTINY) and is also heavily supporting a proposal from Chuck Bennett

(ADEPT). Both proposals are receiving very significant support through the Goddard Bid & Proposal funds pool. Independently, the Jet Propulsion Lab is supporting yet another competitor (JEDI). While we are pleased that NASA and its centers recognize the scientific potential and importance of the JDEM mission, we fear that DOE might be shut out of the field that it, itself, created. We cannot afford to relax at this crucial time as the competition heats up.

We are anxious to compete for the JDEM mission, but this will require increased, not diminished, effort. We believe that the situation has changed very significantly since last year and that the “aggressive” stance of the program is not only appropriate, but, in fact, imperative. We are reacting to the nature of the competition that has been established, and are in the process of reconfiguring the program to fit within the new constraints. Since funding for SNAP commenced, the overall support level has decreased substantially each year, while at the same time the competitive pressures have accelerated. At this point the group is understaffed, given the need to maintain its vigor. We will need to work closely with the OHEP to look for ways to enhance this effort.

In the meantime, SNAP support provides significant enhancement to the activities of various DOE supported university groups. LBNL last year provided significant funding and materials to support technical development work at Yale, Michigan, Caltech, and Indiana. These activities have provided a substantial benefit to the overall health of the US program, and, as an example, have been invaluable in enabling the Dark Energy Survey (DES).

3.1.3 Cosmic Microwave Background

The long-term goal for the CMB program is a precise characterization of the CMB polarization. This will provide insight on the early phase of inflation—thought to be a key element in the puzzle of understanding dark energy. A diverse team of innovators has been assembled to address these challenges, in a partnership with the UCB campus and NERSC. LBNL’s future CMB polarization experiment is POLARBEAR, which is a ground-based CMB observatory to be built in two stages over the next 3-5 years. POLARBEAR has the potential to probe GUT scale energies of 10^{16} GeV, by detecting the fingerprint that inflationary gravity waves (IGW) leave on the curl-component of the polarization. It will make precision measurements of the polarization signal down to angular scales of an arcminute, allowing it to precisely measure the cosmic shear signature. Cosmic shear carries information about the matter distribution and neutrino masses—and must be well understood to measure the IGW signal.

The instrumentation developments for POLARBEAR are stepping stones towards the technology that will ultimately (post-SNAP timescale) be deployed on a CMB satellite mission, which is foreseen as one of NASA’s Beyond Einstein probes. Our team includes a co-Investigator and three collaborators on a NASA proposal to develop a CMB polarization mission. Participation in this mission is a natural progression for both SNAP and CMB personnel on a timeframe beyond 2009.

Another important component of the CMB effort is data analysis and CMB phenomenology, for which the physics division has nurtured a successful partnership with NERSC. This effort is growing, with LBNL playing an important role in the analysis of MAXIPOL (the successor to MAXIMA) data and in preparing algorithms for the ESA Max Planck Surveyor satellite mission, APEX-SZ, and POLARBEAR. LBNL is positioning itself to play an important role in the design and data analysis of a future CMB polarization satellite.

3.2 Accelerator-Based Exploration of the origins of mass

3.2.1 ATLAS

The ATLAS collaboration has started to plan for the pre-operation, operations and research phase of ATLAS. The LBNL construction responsibilities for the silicon strip detector have been met. It is planned to assemble the overall pixel system at CERN starting in mid 2006. Thus a major part of the LBNL ATLAS work will shift to CERN from early 2006 through 2007 in order to assemble, install, commission and first operate those parts of the ATLAS detector that are LBNL responsibilities. Beyond 2007, LBNL will be required to assume operations and maintenance responsibilities for aspects of the pixel detectors. This will require the continued involvement of technical personnel in both the mechanical and electronics aspects of these detectors, in addition to physicists. A continuous presence at CERN by LBNL personnel will be necessary to fulfill these responsibilities. Similarly, support of the initial operations of the framework code and other software developed at LBNL will be critical to the success of ATLAS in its first years of operation. LBNL computing professionals will be needed to provide this support and are resident now at CERN.

The number of physicists at LBNL involved in ATLAS will continue to grow. We anticipate a modest growth in the number of faculty and senior physicists. A more substantial growth in the number of postdoctoral physicists and graduate students is needed for us to meet our detector commitments and have a significant role in the early physics program. We anticipate that more outside university collaborators will join our efforts, which will mitigate some manpower needs.

Completion of the ATLAS detector is now less than two years away, and concepts for upgrades are already under discussion. A major area for potential upgrades is in the tracking detector. The ATLAS design allows the silicon pixel detector to be removed and installed without disturbing substantially the remainder of the tracking detector. One can already foresee the desirability of improvements (e.g. finer granularity, improved radiation hardness, lower mass) to the pixel detector, and R&D to this end should begin in 2006 if one is to be ready to install improved detector elements after the first few years of ATLAS operation.

3.2.2 Linear Collider

We expect the Linear Collider to be the next international accelerator facility to be built. Our efforts on silicon detectors and time projection chambers will continue and will grow as effort on BaBar winds down. Berkeley is universally recognized as a leader in these two technologies under consideration for an ILC detector. Our LDRD in this area provides crucial support for the detector development efforts.

3.2.3 CDF

The effort on CDF will decrease substantially as part of the Physics Division strategy to move resources to ATLAS. Postdocs will not be replaced as they reach the end of their appointments. The group, however, will maintain a reduced program at Fermilab through 2007. Studies of top quark properties will continue. The group has heavily contributed to the development and optimization of the b-tagging algorithm. Work on the top mass measurement, using events with a tagged b jet, will continue. A new method for determining the top mass is being developed by an LBNL postdoc, with contributions from other members of the group. The aim is to reduce the

statistical error by using a novel likelihood procedure.

3.3 Quark and Lepton Flavor Studies

3.3.1 BaBar

The LBNL BaBar Group will continue to be active in the experiment until 2008. The group will continue to work on a number of analysis topics. There are great opportunities at BaBar with the prospects for 500 fb⁻¹ by the end of 2006. This will permit the collaboration to resolve the discrepancies in $\sin 2\beta$ in different channels, make a high-precision measurement of α , make a measurement of γ with moderate precision, make a precise determination of $|V_{cb}|$ and $|V_{ub}|$, and explore the spectroscopy of the $D_{u,d}$ and D_s systems, as well as that of the anomalous charmonium states discovered by BaBar and Belle. In addition, it will be possible to study strong dynamics in weak decays (e.g. $B \rightarrow VV$) and to search for new physics in $B \rightarrow X_s \ell \ell$.

3.3.2 CDF

We will continue to exploit the physics opportunities in RUN II. The LBNL physics interest is centered on precision measurements of CKM matrix parameters. Observation and measurement of B_s mixing and determination of x_s is a hallmark measurement for CDF. In order to resolve these oscillations at large x_s , the proper decay length of B_s must be determined with high precision. This forces CDF to use fully reconstructed decays for the measurement.

3.3.3 Neutrino Physics

Important upgrades are planned to allow KamLAND to be sensitive to solar neutrinos. Strong support from the US-Japan agreement is anticipated to help carry out this effort. The solar neutrino measurements place stringent demands on backgrounds, requiring purification of the scintillator oil. LBNL's Physics and Nuclear Science Divisions are considering joint support of this effort. Possible construction of a National Underground Laboratory is an important opportunity for neutrino physics in the future. Recently, we have obtained support through LDRD to investigate the possibility of a reactor experiment to measure θ_{13} .

4 Conclusion

LBNL has helped to shape high energy physics in the US over the past decades. It has transformed hadron collider physics with the SVX at Fermilab, proposed building an asymmetric electron-positron collider, and then was a major partner in the PEP-II construction and in the design and construction of BaBar, led the development of pixel technology for the LHC, and opened the field of supernova cosmology. This record of innovation is unique in the U.S. program.